# Hearing preservation after cochlear implantation may improve long-term word perception in the electric-only condition

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# Hearing Preservation After Cochlear Implantation May Improve Long-term Word Perception in the Electric-only Condition

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**Objective:** To correlate hearing preservation with word perception in the electric-only condition in recipients of full length cochlear implant (CI) electrode arrays.
**Study Design:** Retrospective chart review.
**Setting:** Tertiary academic referral center.
**Patients:** CI recipients between January 2003 and December 2013 who had measurable residual acoustic hearing before surgery and serial postoperative word perception tests.
**Intervention:** Demographic data, pre- and postoperative pure-tone average, and postoperative monosyllabic word perception scores were evaluated.
**Main Outcome Measure:** Hearing preservation was correlated with postoperative monosyllabic word perception scores.
**Results:** Data from 96 ears in 91 subjects were included. Complete or partial hearing preservation was achieved in 48%. After 6 and 12 months, no significant difference in word perception was found between subjects with and without hearing preservation. However, after 18 or more months, subjects with hearing preservation had significantly better word perception scores (83% versus 72%, $p < 0.05$).
**Conclusion:** Preservation of residual hearing leads to better word perception in the electric-only condition over the long term. CI recipients with hearing preservation continue to make progress after more than 12 months of CI experience whereas those without plateau at 12 months. **Key Words:** Cochlear implant—Cochlear implant outcome—Cochlear implantation—Hearing preservation—Residual hearing—Word perception.

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With the first cochlear implant (CI) models, the insertion of the electrode array into the cochlea was assumed to cause irreversible intracochlear trauma and thereby destroy any residual cochlear function. In 1989, Boggess et al. (1) were the first to demonstrate that preservation of residual hearing after cochlear implantation is possible. Nowadays, minimization of cochlear trauma and/or hearing preservation is attempted in all CI surgeries. Although all surgeries should reduce trauma as much as possible, the following are additional reasons for this goal: 1) in patients with considerable residual low-frequency hearing after cochlear implantation, electro-acoustic stimulation, which allows better speech understanding and music perception, is an option (2,3); 2) the benefit from future treatment options such as stem cell therapy may depend on remaining intact cochlear structures (4); 3) less cochlear trauma leads to less intracochlear fibrosis and ossification (5,6), which simplifies revision surgery.

However, it has not been definitely established that hearing preservation after cochlear implantation with full-length electrodes has an effect on word recognition in the electric-only condition. While Carlson et al. (7), reported significantly better word perception scores in CI recipients with preserved residual hearing, Balkany et al. (8), D'Elia et al. (9), and Cosetti et al. (10) could not demonstrate such an effect.

Therefore, the purpose of this study was to investigate if hearing preservation in CI recipients with full-length CI electrodes is related to word recognition ability in the electric-only condition.

## METHODS

### Subjects

The study was conducted after approval of the Ethical Committee of Zurich (KEK-ZH-Nr. 2015-0430) and in concordance with international standards for human research. A retrospective chart review of 582 cochlear implantations at the University Hospital of Zurich between January 2003 and December 2013 was conducted. To qualify for inclusion, subjects had to be 18 years or older, German speaking, have residual acoustic hearing at any frequency before surgery,

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and to be implanted with a full-length CI electrode array. Subjects were included if a postoperative assessment of residual acoustic hearing and at least three monosyllabic word perception test scores were available after approximately 6 months, 12 months, and 18 or more months after surgery. In subjects who underwent bilateral cochlear implantation, both ears were evaluated separately and included if inclusion criteria were met.

All surgeries were performed using a standard anterior mastoidectomy and posterior tympanotomy approach. After complete visualization of the round window, a cochleostomy anterior and inferior to the round window, or an incision of the round window membrane with a needle, was conducted. Then, the CI electrode array was slowly inserted according to the recommendations of the manufacturer. During the whole procedure, soft-surgical principles were followed. After full insertion of the CI electrode array, the insertion side was sealed with periosteum and the incision closed in layers. Postoperatively, the correct positioning of the CI electrode array was confirmed using a cochlear view x-ray or cone beam computed tomography.

### Audiometric Evaluation

All pure-tone testing was conducted at the University Hospital of Zurich following standard procedures in accordance with ISO 8253-1. Vibrotactile or questionable vibrotactile responses were considered as no response. Hearing preservation after cochlear implantation was assessed using the HEARRING group hearing preservation classification (11). As this classification is scaled to the preoperative pure-tone average (PTA), the effect that worse preoperative hearing tends to produce less postoperative hearing loss and better hearing preservation rates is corrected. Therefore, the classification can be used to evaluate hearing preservation in all CI recipients regardless of the degree of preoperative residual hearing. The PTA is calculated from the hearing thresholds at 125, 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. If no response is present, the maximum audiometer output is entered. The percentage of preserved residual hearing (S) is given by

$$S = 1 - \big((\text{postsurgical PTA} - \text{presurgical PTA})/ (\text{maximum PTA} - \text{presurgical PTA})\big) \times 100[\%].$$

Depending on S, all included subjects were assigned to one of four categories: 1) complete hearing preservation (S >75% of residual hearing preserved), 2) partial hearing preservation (S >25–75%), 3) minimal hearing preservation (S >0–25%), and 4) no measurable hearing (complete loss of hearing, S = 0%).

Pre- and postoperative word perception was assessed using the Swiss version of the German Freiburger monosyllabic word test in quiet (12). Postoperative tests were conducted in the electric-only condition; preoperative tests in the best-aided condition (i.e., with hearing aids and without considering individual ear scores). Percentage of words correctly repeated at a presentation level of 65 dB SPL was determined. If more than one word perception score was available after 18 or more months, then the last assessment was selected for inclusion.

### Statistical Analysis

All statistical analyses were conducted with Stata Statistical Software (Release 13, StataStataCorp LP, College Station, TX, U.S.A.) or GraphPad Prism V5.04 (GraphPad Software, Inc., San Diego, CA, U.S.A.). To compare postoperative word perception scores between subjects with and without hearing preservation, two groups were defined: 1) the hearing preservation group (HP group) included all subjects with complete or partial hearing preservation (Categories 1 and 2 according to the HEARRING group classification); 2) the no hearing preservation group (nHP group), consisting of all subjects with minimal or no hearing preservation (Categories 3 and 4 according to the HEARRING group classification).

## RESULTS

Ninety-six ears in 91 subjects (50 females, 41 males) met the inclusion criteria. According to the HEARRING group hearing preservation classification, complete hearing preservation was achieved in 11 ears (12%), partial in 35 (36%), and minimal in 21 (22%). In 29 ears (30%), the residual hearing was completely lost. Therefore, the HP group consisted of 46 ears (48%), the nHP group of 50 (52%). Table 1 summarizes the demographic data for each group.

The HP group consisted of 27 females (59%), the nHP group of 26 (52%) ($p = 0.51$). In the HP group 27 (59%) and in the nHP group 26 (52%) CIs were implanted on the right side ($p = 0.51$). Mean age at implantation was 46 years (range from 19 to 80 yr) in the HP group and 52 years (range from 18 to 89 yr) in the nHP group ($p = 0.06$). In the HP group mean duration of deafness was 21 years (SD 12 yr), in the nHP group 23 years (SD 16 yr) ($p = 0.87$). A cochleostomy anterior and inferior to the round window was performed in 24 ears (48%) of the HP group and 42 ears (84%) of the nHP group ($p < 0.01$). In the HP group 23 CI24RE, 21 CI422, and 2 HiRes90K Advantage were implanted compared with 42 CI24RE and 8 CI422 in the nHP group ($p < 0.01$).

The mean preoperative word perception score was 16% (SD 26%) in the HP group compared with 11% (SD 21%) in the nHP group ($p = 0.83$). The mean preoperative PTA was 89 dB HL (SD 11 dB) in the HP group and 96 dB HL (SD 9 dB) in the nHP group ($p < 0.05$). For both groups combined, the mean preoperative PTA was 93 dB HL (SD 10 dB) and the mean postoperative PTA 103 dB HL (SD 7 dB). In the contralateral ear, the mean preoperative PTA was 88 dB HL (SD 15 dB) and the mean postoperative PTA 89 dB HL (SD 15 dB) (Fig. 1). On average, postoperative pure-tone audiograms were conducted 35 days after surgery (SD 12 d).

The mean postoperative word perception score in the electric-only condition after approximately 6 months (mean 134 d, SD 32 d) was 65% (SD 25%) in the nHP group and 67% (SD 24%) in the HP group ($p = 0.6$). After approximately 12 months (mean 309 d, SD 115 d), the mean word perception score was 71% (SD 25%) in the nHP group and 79% (SD 22%) in the HP group ($p = 0.05$). In the latest assessment after 18 or more months of CI experience (mean 783 d, SD 355 d), the mean word perception score of 72% (SD 25%) of the nHP group was significantly lower compared with the mean word perception score of 83% (SD 17%) of the HP group (Kruskal–Wallis test with Dunn's multiple test correction, $p < 0.05$). Figure 2 summarizes the changes over time of the mean word perception score in both groups.

**TABLE 1.** *Comparison of demographic and audiometric data between the hearing preservation (HP) and no hearing preservation (nHP) groups*

| | Hearing Preservation (HP) | No Hearing Preservation (nHP) | *p* |
|---|---|---|---|
| Total (n) | 46 | 50 | |
| Sex: female (n,%) | 27 (51) | 26 (52) | 0.51[a] |
| Side: right (n,%) | 27 (51) | 26 (52) | 0.51[a] |
| Mean age at implantation (yr: mean, range) | 46 (19–80) | 52 (18–89) | 0.06[b] |
| Duration of deafness (yr: mean, SD) | 21 (12) | 23 (16) | 0.87[b] |
| Cochlear implant model | | | *<0.05[c] |
| CI24RE | 23 | 42 | |
| CI422 | 21 | 8 | |
| HiRes90K advantage | 2 | 0 | |
| Surgical approach: cochleostomy (n,%) | 24 (48) | 42 (84) | *<0.05[a] |
| Mean preoperative PTA (dB HL: mean, SD)[d] | 89 (11) | 96 (9) | *<0.05[b] |
| Mean preoperative speech perception (%: mean, SD)[e] | 16 (26) | 11 (21) | 0.38[b] |

[a]Pearson $\chi^2$ test.
[b]Wilcoxon rank sum test.
[c]Fisher's exact test.
[d]PTA was calculated from the hearing thresholds at 125, 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz.
[e]Preoperative word perception in the best-aided condition.
*Indicates statistical significance at $p < 0.05$.
PTA indicates pure-tone average.

Given the discrepancy regarding cochlear implant model, surgical approach, and preoperative PTA between the HP and the nHP group, further analyses were performed. There was no significant relationship between the word perception score after 18 or more months and the cochlear implant model (CI24RE versus CI422, Wilcoxon rank-sum test, $p = 0.8$) and between the word perception score after 18 or more months and the surgical approach (cochleostomy versus round window insertion, Wilcoxon rank-sum test, $p = 0.8$). Two tests were performed regarding the relationship between the word perception score after 18 or more months and the preoperative PTA. No significant relationship was found using a linear regression analysis (Spearmans rank correlation test, $p = 0.2$). Furthermore, a Wilcoxon rank-sum test comparing the word perception score after 18 or months between the better half of the population regarding preoperative PTA (mean PTA 73 dB HL, SD 25 dB) and the worse half (mean PTA 81 dB HL, SD 18 dB) was conducted. There was also no significant relationship ($p = 0.2$).

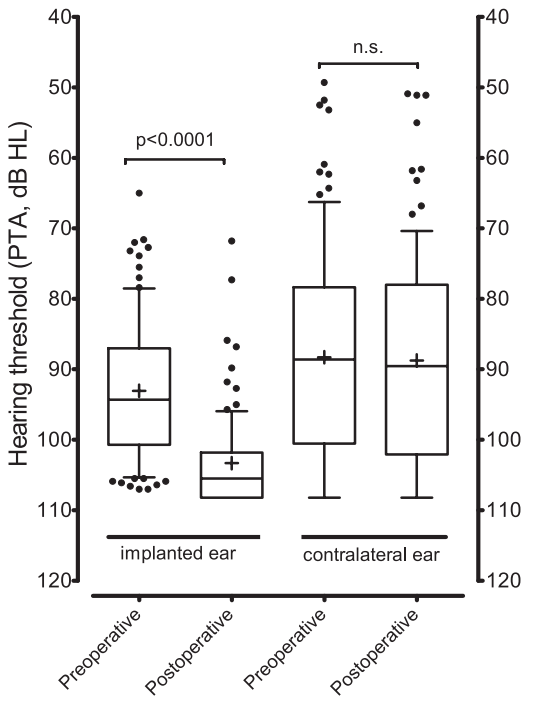


**FIG. 1.** Mean pre- and postoperative pure-tone average (PTA) in the implanted and the contralateral ear (*whiskers* mark the 10th and 90th percentiles, + marks the mean).

## DISCUSSION

Our results suggest that word perception scores in the electric-only condition are improved over the long term in CI recipients when residual hearing is preserved. Monosyllabic word perception scores were not statistically different between the HP and nHP groups at 6 and 12 months, whereas the HP group had significantly better word perception after 18 or more months of CI experience (mean word perception score after 18 or more months 83% in the HP group versus 72% in the nHP group, $p < 0.05$, corrected for multiple tests). This suggests that progress in word recognition abilities after more than 12 months, as described in previous studies (13,14), is more likely if intact cochlear structures are preserved. Overall, these findings further support the notion that preservation of residual hearing should be attempted in all CI recipients, even those with minimal or nonfunctional residual acoustic hearing before surgery.

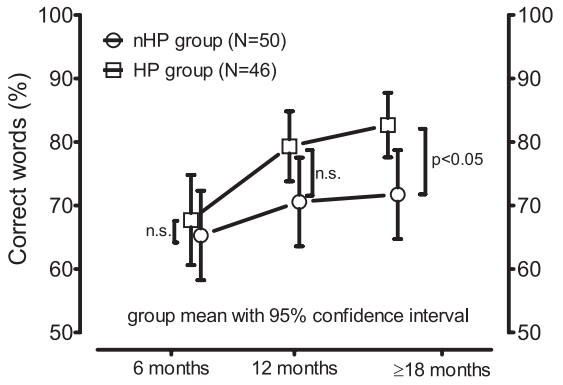


**FIG. 2.** Changes of the mean monosyllabic word perception score as a function of time in the electric-only condition in the hearing preservation (HP) and the no hearing preservation (nHP) group.

The assessment of residual acoustic hearing close to the maximum output of the audiometer leads to a ceiling effect causing an underestimation of the postoperative hearing loss and an overestimation of hearing preservation rates. To take this effect into account, different hearing preservation classifications have been proposed (7–10,15). The advantage of the HEARRING group hearing preservation classification system (11) is that the postoperative PTA is related to the preoperative PTA. Therefore, the classification considers the relative change of the hearing threshold, which makes it suitable especially in CI recipients with minimal acoustic hearing before surgery. For this study, cases with complete and partial hearing preservation according to the HEARRING group classification were included in the HP group, whereas the nHP group was defined as subjects with minimal hearing preservation or complete loss of residual hearing. We assigned subjects with minimal hearing preservation according to the HEARRING group classification to the nHP group. The reason was that in our population—with already limited residual hearing before surgery (mean preoperative PTA 93 dB HL, SD 10 dB)—the mean postoperative PTA in those subjects was 106 dB HL (SD 2 dB). This PTA is only 2 dB less than the maximum PTA of 108 dB HL and therefore corresponds to measurable postoperative hearing at only one or two frequencies.

Complete or partial hearing preservation could be achieved in 48% of the included subjects. Although hearing preservation rates reported in the literature vary greatly, this rate is comparable to other reports that investigated hearing preservation rates with full-length CI electrodes (15–17).

Significant differences between the HP and nHP groups existed regarding CI electrode array type used, surgical approach, and mean preoperative PTA. However, there were no other significant differences, especially regarding age at implantation, duration of deafness, and preoperative speech perception, factors known to influence speech perception after cochlear implantation (18,19). Furthermore, the CI electrode used, the surgical approach, and the preoperative PTA showed no significant association with the postoperative word perception score after 18 or more months.

Differences between the HP and the nHP groups regarding CI electrode array types and the surgical approach were expected due to the following reasons: hearing preservation rates vary between different CI electrode array types (16,20), and the surgical approach is usually given by the electrode array type used. Therefore, the difference between both groups regarding the surgical approach reflects the difference regarding CI electrode array types used. However, the difference in postoperative word recognition abilities between both groups cannot be explained by differences in CI electrode array types (19).

To address the aim of this study, we correlated hearing preservation with postoperative monosyllabic word perception scores and found significantly better word perception scores in the HP group compared with the nHP group after 18 or more months of CI experience. Interestingly, the difference became significant only over the long term. After 6 months, word perception scores were only marginally different between both groups (65% in nHP group versus 67% in the HP group, $p = 0.6$). After 12 months, both groups had improved mean word perception scores and the difference had increased but not reached statistical significance (71% in the nHP group versus 79% in the HP group, $p = 0.053$).

Carlson et al. (7) reported similar findings. They found significantly better monosyllabic word perception scores in CI recipients with hearing preservation compared with patients with complete hearing loss. However, they did not report word perception scores at different time points after surgery but analyzed the latest assessment in each patient. This resulted in a mean CI experience at the time of testing of 35.7 months and was therefore well beyond 12 months. Together with our findings, this suggests that hearing preservation improves word perception in the electric-only condition, but the effect occurs with a delay of more than 12 months. This could explain why other studies have reported no significant difference regarding word perception between patients with and without preservation of residual cochlear function. In the studies of Balkany et al. (8), D'Elia et al. (9), and Cosetti et al. (10), the mean postoperative follow-up was 12 months or less. Still, although D'Elia et al. found no significant difference in speech perception scores, they did find a correlation between hearing preservation and a larger dynamic range, which has been associated with better word perception in CI users in other studies (21,22).

Several reasons could be responsible for the difference in word perception between CI recipients with and without hearing preservation in the electric-only condition that are not likely related to the preserved residual hearing itself. The conservation of residual hearing is more likely a surrogate marker for preserved cochlear structures, which consequently allow a more distinct electrical stimulation and thereby better word perception abilities.

The underlying rationale is that to benefit from a CI, the presence of functional neural fibers is crucial. Although the number of undamaged neural fibers necessary to obtain a good functional outcome with a CI is controversial and some temporal bone studies have found no correlation between speech recognition and the number of spiral ganglion cells (23–25), results in animals suggest that the number of viable neural fibers should be the highest possible to obtain the best electrical stimulation (26). Additionally, animal studies have shown that avoidance of injury and the preservation of the organ of Corti is important for the long-term survival of spiral ganglion cells and dendrites (27–29). This could explain why conservation of as much of the cochlear structures as possible and thereby preserving residual hearing may allow preservation of more intact neural fibers over the long term and better word perception abilities in the electric-only condition.

Apart from that, suboptimal placement of the CI electrode array itself could also diminish word perception abilities. As suboptimal placement of the CI electrode array is almost necessarily associated with more cochlear trauma and thereby loss of cochlear function, loss of residual hearing could serve as a surrogate marker. Possible reasons why suboptimal placement could decrease speech perception are less distinct ganglion neural population stimulation and an increased risk of wide spread electrical stimulation. Imaging studies have shown that scalar dislocations of the CI electrode array are associated with decreased CI outcomes regarding speech perception (30,31). However, whether this difference in speech perception is a consequence of the cochlear damage or a result of the misplacement of the electrode array itself is unknown.

Finally, cochlear trauma during surgery and thereby loss of residual hearing leads to reactive fibrosis and ossification inside the cochlea and around the electrode array (5). Such changes could also diminish the ability to stimulate intact neural fibers selectively and thereby be the reason for the plateau in word perception over the long term in the nHP group.

The fact that the difference in word recognition score between the HP and nHP groups probably arises from changes of cochlear and neural structures for which residual hearing can only be used as a surrogate marker represents—in addition to the retrospective character of the analysis—a limitation of this and similarly designed studies. However, histological specimens that can be correlated with speech recognition abilities are very limited, and imaging studies are capable of reliably detecting scalar dislocation of the electrode array, but not of providing data regarding changes of cochlear or neural structures. There is to date a lack of other well-established methods to determine cochlear changes and correlate such changes with CI outcomes.

## CONCLUSION

Preservation of residual hearing leads to better word perception in the electric-only condition. However, the effect becomes evident only after more than 18 months of CI experience.

## REFERENCES


1. Boggess WJ, Baker JE, Balkany TJ. Loss of residual hearing after cochlear implantation. *Laryngoscope* 1989;99:1002–5.
2. Irving S, Gillespie L, Richardson R, et al. Electroacoustic stimulation: Now and into the future. *Biomed Res Int* 2014;2014: 350504.
3. Adunka OF, Dillon MT, Adunka MC, et al. Hearing preservation and speech perception outcomes with electric-acoustic stimulation after 12 months of listening experience. *Laryngoscope* 2013;123:2509–15.
4. Senn P, Oshima K, Teo D, et al. Robust postmortem survival of murine vestibular and cochlear stem cells. *J Assoc Res Otolaryngol* 2007;8:194–204.
5. Somdas MA, Li PM, Whiten DM, et al. Quantitative evaluation of new bone and fibrous tissue in the cochlea following cochlear implantation in the human. *Audiol Neurootol* 2007;12: 277–84.
6. Ryu KA, Lyu AR, Park H, et al. Intracochlear bleeding enhances cochlear fibrosis and ossification: An animal study. *PLoS One* 2015;10:e0136617.
7. Carlson ML, Driscoll CL, Gifford RH, et al. Implications of minimizing trauma during conventional cochlear implantation. *Otol Neurotol* 2011;32:962–8.
8. Balkany TJ, Connell SS, Hodges AV, et al. Conservation of residual acoustic hearing after cochlear implantation. *Otol Neurotol* 2006;27:1083–8.
9. D'Elia A, Bartoli R, Giagnotti F, et al. The role of hearing preservation on electrical thresholds and speech performances in cochlear implantation. *Otol Neurotol* 2012;33:343–7.
10. Cosetti MK, Friedmann DR, Zhu BZ, et al. The effects of residual hearing in traditional cochlear implant candidates after implantation with a conventional electrode. *Otol Neurotol* 2013;34:516–21.
11. Skarzynski H, van de Heyning P, Agrawal S, et al. Towards a consensus on a hearing preservation classification system. *Acta Otolaryngol Suppl* 2013;3–13.
12. Kompis M, Krebs M, Hausler R. Verification of normative values for the Swiss version of the Freiburg speech intelligibility test. *HNO* 2006;54:445–50.
13. Dillon MT, Buss E, Adunka MC, et al. Long-term speech perception in elderly cochlear implant users. *JAMA Otolaryngol Head Neck Surg* 2013;139:279–83.
14. Ruffin CV, Tyler RS, Witt SA, et al. Long-term performance of Clarion 1.0 cochlear implant users. *Laryngoscope* 2007;117:1183–90.
15. Anagiotos A, Hamdan N, Lang-Roth R, et al. Young age is a positive prognostic factor for residual hearing preservation in conventional cochlear implantation. *Otol Neurotol* 2015;36:28–33.
16. Van Abel KM, Dunn CC, Sladen DP, et al. Hearing preservation among patients undergoing cochlear implantation. *Otol Neurotol* 2015;36:416–21.
17. Hunter JB, Gifford RH, Wanna GB, et al. Hearing preservation outcomes with a mid-scala electrode in cochlear implantation. *Otol Neurotol* 2016;37:235–40.
18. Friedland DR, Runge-Samuelson C, Baig H, et al. Case-control analysis of cochlear implant performance in elderly patients. *Arch Otolaryngol Head Neck Surg* 2010;136:432–8.
19. Holden LK, Finley CC, Firszt JB, et al. Factors affecting open-set word recognition in adults with cochlear implants. *Ear Hear* 2013;34:342–60.
20. Fraysse B, Macias AR, Sterkers O, et al. Residual hearing conservation and electroacoustic stimulation with the nucleus 24 contour advance cochlear implant. *Otol Neurotol* 2006;27: 624–33.
21. Kawano A, Seldon HL, Clark GM, et al. Intracochlear factors contributing to psychophysical percepts following cochlear implantation. *Acta Otolaryngol* 1998;118:313–26.

22. Blamey PJ, Pyman BC, Gordon M, et al. Factors predicting postoperative sentence scores in postlinguistically deaf adult cochlear implant patients. *Ann Otol Rhinol Laryngol* 1992;101: 342–8.
23. Nadol JB Jr, Shiao JY, Burgess BJ, et al. Histopathology of cochlear implants in humans. *Ann Otol Rhinol Laryngol* 2001;110:883–91.
24. Fayad JN, Linthicum FH Jr. Multichannel cochlear implants: Relation of histopathology to performance. *Laryngoscope* 2006;116:1310–20.
25. Gassner HG, Shallop JK, Driscoll CL. Long-term clinical course and temporal bone histology after cochlear implantation. *Cochlear Implants Int* 2005;6:67–76.
26. Pfingst BE, Sutton D, Miller JM, et al. Relation of psychophysical data to histopathology in monkeys with cochlear implants. *Acta Otolaryngol* 1981;92:1–13.
27. Leake PA, Hradek GT, Snyder RL. Chronic electrical stimulation by a cochlear implant promotes survival of spiral ganglion neurons after neonatal deafness. *J Comp Neurol* 1999;412:543–62.
28. Spoendlin H. Factors inducing retrograde degeneration of the cochlear nerve. *Ann Otol Rhinol Laryngol Suppl* 1984; 112:76–82.
29. Sugawara M, Corfas G, Liberman MC. Influence of supporting cells on neuronal degeneration after hair cell loss. *J Assoc Res Otolaryngol* 2005;6:136–47.
30. Finley CC, Holden TA, Holden LK, et al. Role of electrode placement as a contributor to variability in cochlear implant outcomes. *Otol Neurotol* 2008;29:920–8.
31. Aschendorff A, Kromeier J, Klenzner T, et al. Quality control after insertion of the nucleus contour and contour advance electrode in adults. *Ear Hear* 2007;28:75S–9S.